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Spatiotemporal Evolution Characteristics of Ecosystem Service Values Based on NDVI Changes in Island Cities

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ABSTRACT Vegetation plays a dominant role in and serves as the structural foundation of island-land ecosystems. Island cities, as sea-land ecological complexes, are able to somewhat reflect the general realities of island ecological environments. By using the Landsat series remote-sensing images and an ecosystem service value (ESV) evaluation system, in this paper, the temporal and spatial evolution characteristics of the NDVIs and ESVs of China's 12 island counties over the past three decades are analyzed. According to the research results, (1) The average NDVI of China's island counties dropped from 0.380 to 0.347 in 1990-2018, reflecting a continuous downtrend. The NDVIs of Changhai County and Changdao County show significant changes, with decreases of 45.24% and 37.57%, respectively. (2) The total ESV of China's island counties showed a ''V''-shaped change trend from 1990-2018; the minimum value reached USD 362 million in 2010, then essentially recovered to the 2000 level in 2018. (3) The high and low values of NDVI and ESV in island counties over the years were distributed with the spatial characteristics of high values in the center of the islands and low values at the edges of the islands. The island counties north of the Yangtze River showed the largest changes in NDVI and ESV. (4) Forest cover is the main factor that drives ESV reduction in China's island counties, followed by grassland cover. This study provides an effective method to study the changes in the NDVI and ESV of island cities and proposes the strengthening of island vegetation protection and the promotion of sustainable development in the ecological environments and economies of island cities.

INDEX TERMS Spatiotemporal evolution characteristics, ecosystem service values, NDVI, island cities.

I. INTRODUCTION

Vegetation is a critical ecological factor affecting ecosystems, and vegetation cover and changes in vegetation cover are important indicators that reflect ecosystem changes [1], [2]. The normalized difference vegetation index (NDVI), the optimum indicator of vegetation growth and cover and an effective index for monitoring regional and global vegetation and ecological environments [3], [4], has been widely used in the study of vegetation dynamics [5], vegetation dynamic analysis [6], [7], land cover change detection [8], ecosystem assessment [9], etc. Vegetation is an important factor affecting ecosystem services, as it penetrates the whole process of the cycle of matter, the flow of energy and information transmission in the ecosystem by connecting the soil-plant-atmosphere elements [10], [11]. The economic value of ecosystem services is subject to the interactions between ecosystem supply and social demand [12], [13], which is usually quantified by the direct benefit transfer method [12], [14], [15]. At present, NDVI has been effectively applied in assessments of the ecosystem service values [16], [17] of forests, grasslands, wetlands, and so on; however, there are very few studies on island areas.

An island represents the convergence of terrestrial and marine ecology, and vegetation is the main body and structural basis of island-mainland ecosystems [18]. An island is an independent and complete eco-environment region [18]. The island ecosystem is characterized by special location, spatial isolation, bedrock exposure, low vegetation cover, and high ecological vulnerability [19], [20]. The special habitat,

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vegetation composition and vegetation ecosystem of an island are all vulnerable to a variety of disturbances [21], [22]. Once damaged, it is difficult for an island ecosystem to achieve self-rehabilitation. The restoration and governance of island ecosystems will be increasingly difficult and has become an important component of the control of island ecological spaces [23]. In an island ecosystem, the species and quantity of wild animals are limited, and vegetation plays a dominant role [24], [25] because of this, island vegetation restoration has become a key link in protecting and improving island ecosystems. It is of great importance to strengthen the research on NDVI and ecosystem service values associated with island areas.

An island city is an integrated region established according to the requirements of administrative units. An island city consists of island groups, island chains or independent islands along a coastline; inhabited islands compose the main body, with adjacent scattered uninhabited islands [26], [27]. As important links between land and sea, island cities are a key connection in land-and-sea-integrated planning. An island city, which is a special natural complex that covers a small area, is isolated and self-contained [28]. The development of island cities is interwoven with economic vulnerability, environmental vulnerability, and social vulnerability [29], which, to a certain extent, is typical and representative of the overall situation of the ecological environment and the economic and social development of islands. Scholars have carried out relevant studies on the ecosystems of island cities. Wu *et al.* [26] conducted research on the ecological security of island cities. Ceres *et al.* [30] studied disaster prevention in island cities. Lapointe *et al.* [31] studied the ecosystem services of island countries from the perspective of urbanization. However, there are very few studies on the ecosystem service values of island cities from the perspective of NDVI change.

In this study, 12 island counties (cities, districts) in China were selected as the research objects. Landsat series remote sensing data are used for the first time in analyses of the vegetation of island counties in China, and the annual average NDVI and its variation trend are calculated for island counties in China from 1990 to 2018 on temporal and spatial scales. In addition, the ESV sensitivity coefficient was introduced to test the ESV calculation results, making the calculation results more scientific. The research enriches the methods and theories of ecosystem service value evaluation in island areas, and the research results can provide a scientific reference for government departments to carry out island ecological protection and ecological management, aiming to promote the sustainable use of island city resources and the sustainable management of ecosystems.

II. MATERIALS AND METHODS

A. STUDY AREA

China is a major maritime country with more than 11,000 islands [32], of which over 400 are inhabited. China has 12 island counties that are distributed in the Yellow Sea, the East China Sea and the South China Sea (Fig. 1). From north to south, these 12 island counties are Changhai County, Changdao County, Chongming District, Shengsi County, Daishan County, Dinghai District, Putuo District, Yuhuan city, Dongtou District, Pingtan County, Dongshan County and Nan'ao County [33], [34]. These island counties consist of 1,738 islands of various sizes, accounting for 26.7% of the nation's total number of islands. Of the 1,738 islands in the island counties listed above, 176 are inhabited, accounting for 42% of the national inhabited islands. These island counties cover a total land area of 4200 square kilometers and have a total combined population of 3.41 million with a population density of 812 people/km2.

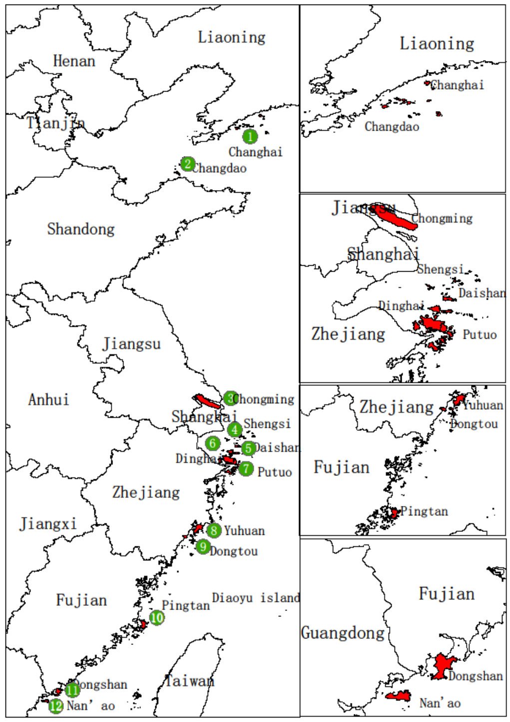

FIGURE 1. Locations of the study areas.

Among them, Chongming District covers the largest area, 1,413 square kilometers, while Changdao County has the smallest area at 56.35 square kilometers; Pingtan County has the highest population density, while Changhai County has the lowest population density; Yuhuan city has the highest GDP, reaching RMB 5.81E + 10, while Nan'ao County has the lowest GDP of RMB 1.92E + 9. The climate types, from north to south, are: warm subhumid monsoon climate, warm continental monsoon climate, subtropical monsoon climate, subtropical marine monsoon climate, subtropical monsoon climate and south subtropical monsoon climate. The resources and environmental conditions of each island county vary (Table 1).

B. DATA SOURCE AND PROCESSING

In this study, Landsat series remote sensing images are used and are obtained from the United States Geological

TABLE 1. Description of the areas, populations and natural environments of China's island counties.

Island county	Province	Area (km^2)	Population	Climate type	GDP (10^8yuan)
Changhai	Liaoning	120.76	71226	Warm subhumid monsoon climate	95
Changdao	Shandong	56.35	41489	warm continental monsoon climate	74.37
Chongming	Shanghai	1413	678000	Subtropical monsoon climate	351.14
Shengsi	Zhejiang	80.7	74389	Subtropical marine monsoon climate	114.3
Daishan	Zhejiang	278.4	176425	Subtropical marine monsoon climate	215.5
Dinghai	Zhejiang	568.8	496100	Subtropical marine monsoon climate	548.93
Putuo	Zhejiang	459	393100	Subtropical marine monsoon climate	437.5
Yuhuan	Zhejiang	378	628000	Subtropical marine monsoon climate	580.77
Dongtou	Zhejiang	172.50	102000	Subtropical monsoon climate	101.15
Pingtan	Fujian	319.26	451700	Subtropical monsoon climate	282.85
Dongshan	Fujian	221.59	221716	Subtropical monsoon climate	257.68
Nan'ao	Guangdong	106.17	76248	South subtropical monsoon climate	19.18

Survey (USGS) with a spatial resolution of 30 m and a temporal resolution of 16 days. Among them, Landsat 4-5 TM satellite digital remote sensing images are used for 1990, 2000 and 2010, while Landsat 8 OLI_TIRS satellite digital remote sensing images are used for 2018. ENVI5.3 software is used for the processing of remote sensing images with cloud cover values lower than 3 per year; the processing includes radiometric calibration, atmospheric correction, geometric correction, image clipping, and NDVI calculation. Then, the ArcGIS 10.2 spatial analysis tool is used to determine pixel superposition statistics of NDVI images, in each period of the year, to obtain the annual composite values of NDVI. A total of 216 remote sensing images of 12 island counties were used. In addition, relevant population, economy and land cover data were obtained from the Statistical Bulletin on National Economic and Social Development and from the official statistical yearbook of the city, which has jurisdictions over specific island counties.

C. METHODOLOGY

1) NDVI CALCULATION

The normalized difference vegetation index (NDVI) is a common index that measures regional vegetation cover. The value of NDVI is in the range of [−1, 1], and NDVI is positively correlated with vegetation biomass [35], [36]. In this study, the NDVI values of island counties in China are calculated using the band operation tool of the ENVI5.3 software. The formula is as follows (Eq. (1)):

$$NDVI = (IR - R)/(IR + R) \tag{1}$$

where IR is the near-infrared band in the remote sensing images and R is the infrared band.

2) CALCULATION OF ECOSYSTEM SERVICE VALUES BASED ON NDVI

The NDVI value varies for different ecosystems. According to studies by Rouse (1974), take (1979), and Uddin (2015) [37]–[39], the average NDVI of forestland is greater than 0.5, that of farmland is 0.3-0.5 and that of grassland is 0.1-0.3; the average NDVI of barren land, which includes lakes, rivers, and buildings, is less than 0.1 [40], [41] (Table 2).

TABLE 2. Average NDVI values and corresponding land cover types.

NDVI	Corresponding land covers
> 0.5	Forestlands
0.3-0.5	Croplands
0.1-0.3	Grasslands
< 0.1	Barren lands

TABLE 3. Ecosystem service value coefficients of different ecosystem types.

Land cover types	Ecosystem Service Values (USD ha−1, yr−1)
Swamp/wetland	8939.26
Forestlands	2168.84
Shrub lands	1089.19
Grasslands	565.88
Croplands	699.37
Barren lands	59.83

The ESV of each land cover type in the island counties was determined based on previous studies by Costanza *et al.* [42] and Xie *et al.* [43] (Table 3).

Eq. (2) was used to calculate the ecosystem service value coefficients of the island counties using the equivalent coefficient value of the services and functions of each ecosystem:

$$ESV = (\sum A_k VC_k) \tag{2}$$

where ESV is the ecosystem service value, A_k is the area (hectare) of "k" for each land cover type, and VC_k is the coefficient value of the ecosystem services (USD/ha · year). In addition, Eq. (3) was used to calculate the relationship between the available ESV per person and the population of each island county:

$$ESV(USD/head) = \frac{ESV_{total}}{N} \tag{3}$$

where ESV_{total} is the total ecosystem service value (USD/year), and N is the population of the island county.

3) ESV SENSITIVITY ANALYSIS

This study used a sensitivity coefficient to determine the degree of dependence of the changes in ESV over time on changes in the ESV coefficient. The sensitivity coefficient refers to the effect of a 1% change in the ESV coefficient on the ESV. Eq. (4) was used to calculate the sensitivity coefficient:

$$CS = \left| \frac{(ESV_j - ESV_i)/ESV_i}{(VC_j - VC_i)/VC_i} \right| \tag{4}$$

where CS represents the sensitivity coefficient; ESV_i and ESV_j represent the initial ESV and the adjusted ESV, respectively; and VC_i and VC_j are the initial ESV coefficient and the adjusted ESV coefficient, respectively.

4) CALCULATION OF ECOSYSTEM SERVICE VALUES BASED ON SUPERVISED CLASSIFICATION

To compare the ecosystem service values calculated based on NDVI, in this paper, the land cover types are classified based on the supervised classification of remote sensing images of island counties, and the ecosystem service value of each island county is calculated. ENVI5.3 software was used to preprocess remote sensing images such as radiation calibration, atmospheric correction, image clipping, etc. According to the spectral properties of surface features in remote sensing images and in Google Earth images, the land cover types of each island county are classified into forestland, grassland, farmland, barren land (including buildings and wasteland), water system and wetland using the method of supervised classification. Then, based on the methods in previous studies by Costanza (1997) and Xie *et al.* (2003), the ESV of each land type in each island county is calculated using Eq. 2 (Table 3), and the difference between the ESV calculation results of the two methods is calculated by Eq. (5):

$$DR = \frac{ESV_{NDVI} - ESV_{SC}}{ESV_{SC}} \tag{5}$$

where DR is the difference between the two ESV calculation results, ESV_{NDVI} is the ESV result calculated based on NDVI, and ESV_{SC} is the ESV result calculated based on the supervised classification of remote sensing images.

III. RESULTS

A. TEMPORAL-SPATIAL VARIATION OF THE NDVIs OF ISLAND COUNTIES IN CHINA FROM 1990 TO 2018

From 1990 to 2018, the average NDVI of the 12 studied island counties in China showed a downward trend, with a decline rate of 8.79% (Table 4). Changhai County had the largest rate of decline, reaching 45.24%, followed by Changdao County and Chongming District, with decline rates of 37.57% and 17.91%, respectively. The NDVIs of Dinghai District, Putuo District, Yuhuan city and Nan'ao County increased. The highest average NDVI value appeared in Nan'ao County, and the average NDVI values in Nan'ao County ranged from 0.504-0.599. The lowest average NDVI value appeared in Chongming District, and the average NDVI values in Chongming District ranged between 0.154 and 0.188.

From a spatial point of view, there are significant differences in the distribution of NDVI among the island counties (Fig. 2), which is related to the topographical ecosystem characteristics of each island. However, in general, higher NDVIs are generally concentrated in the foothills and in the hilly areas of the central areas of the islands, while the flat land and tidal flats at the edge of the islands have lower NDVIs. The foothills and hilly areas of each island are subject to less natural disturbance and human interference than the flat lands, and the vegetation in hilly areas is well maintained. However, due to the long-term influence of sea wind and waves and large amounts of human interference, the vegetation coverage of the edge areas of each island will generally be lower than that of the central area.

TABLE 4. Changes in NDVI of island counties in China from 1990 to 2018.

Island county	1990	2000	2010	2018	Rate of change
Changhai	0.497	0.405	0.353	0.272	-45.24%
Changdao	0.384	0.458	0.464	0.239	-37.57%
Chongming	0.188	0.164	0.159	0.154	-17.91%
Shengsi	0.391	0.403	0.320	0.361	-7.51%
Daishan	0.382	0.509	0.471	0.327	-14.38%
Dinghai	0.448	0.526	0.567	0.495	10.51%
Putuo	0.486	0.394	0.410	0.535	10.11%
Yuhuan	0.202	0.257	0.245	0.278	37.71%
Dongtou	0.253	0.172	0.210	0.218	-13.87%
Pingtan	0.463	0.301	0.296	0.391	-15.67%
Dongshan	0.365	0.329	0.333	0.343	-6.12%
Nan'ao	0.504	0.599	0.567	0.547	8.60%
Average	0.380	0.376	0.366	0.347	-8.79%

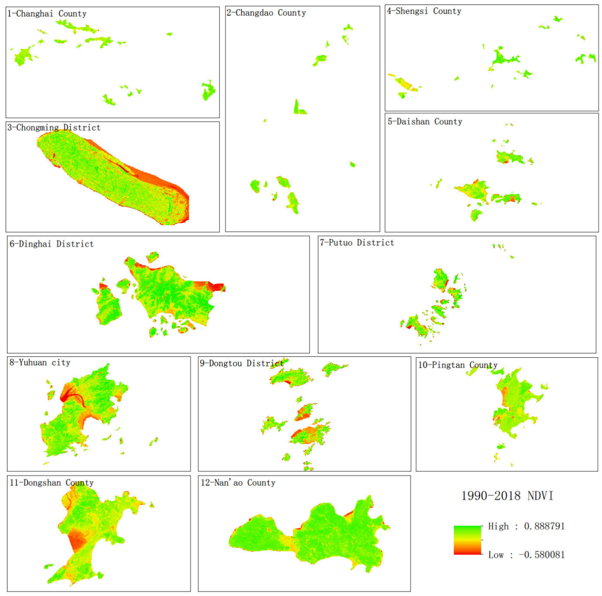

FIGURE 2. Spatial distribution of the NDVIs in island counties in China from 1990 to 2018.

B. SPATIO-TEMPORAL VARIATION IN ESV OF ISLAND COUNTIES OF CHINA FROM 1990 TO 2018

From 1990 to 2018, the total ESV of China's 12 island counties changed from 380 million U.S. dollars, 370 million U.S. dollars, 362 million U.S. dollars, to 371 million U.S. dollars,

TABLE 5. Changes in ESV of different ecosystems in island counties in China from 1990 to 2018.

Land cover type	ESV（USD yr^{-1}）				ESV Changes（%）			
	1990	2000	2010	2018	1990-2000	2000-2010	2010-2018	1990-2018
Forestlands	2.38E+08	2.29E+08	2.29E+08	2.12E+08	-3.86%	-0.17%	-7.55%	-11.27%
Croplands	6.01E+07	5.90E+07	4.29E+07	6.08E+07	-1.67%	-27.43%	41.97%	1.30%
Grasslands	7.77E+07	7.70E+07	8.42E+07	9.41E+07	-0.85%	9.29%	11.80%	21.15%
Barren lands	3.65E+06	4.65E+06	5.72E+06	4.39E+06	27.30%	22.97%	-23.18%	20.26%

showing a "V"-shaped change trend in general. The total ESV in 2010 was lower than those in 1990, 2000 and 2018. The highest ESV occurred in forestlands. In 2018, the ESV of forestlands was 2.12E + 8 USD, which is lower than those in 1990, 2000 and 2010. The ESV of grassland was higher than those of farmland and barren land (Table 5). At present, ESV in forestland has decreased. Between 1990 and 2018, the ESV of forestland decreased by 0.26E + 8 USD, but the ESVs of farmland, grassland and barren land increased. The ESV of farmland increased by 1.30%, the ESV of grassland increased by 21.15%, and the ESV of barren land increased by 20.26% (Table 5).

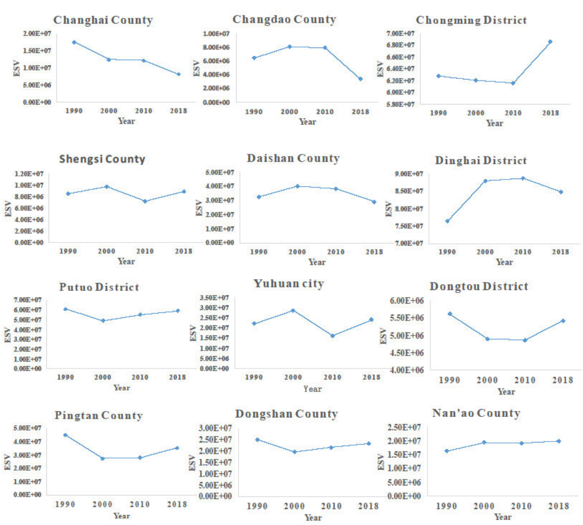

FIGURE 3. Changes in the ESVs of island counties in China from 1990 to 2018.

In terms of individual island counties, the ecosystem service values of 7 out of the 12 island counties showed downward trends (Fig. 3). Among them, Changhai County had the highest rate of decline of ESV, reaching 53.14%, followed by Changdao County with a decline rate of 48.58%. In addition, the ESVs of Daishan County, Putuo District, Dongtou District, Pingtan County and Dongshan County decreased by 10.57%, 3.04%, 3.54%, 21.02% and 6.77%, respectively. The ESV of Chongming District, Shengsi County, Dinghai District, Yuhuan city and Nan'ao County increased. Among them, the growth rate of the ESV in Nan'ao County was the highest, reaching 22.03%, and those of Chongming District, Shengsi County, Dinghai District and Yuhuan city increased by 9.16%, 4.55%, 11.06% and 9.36%, respectively.

In addition, in terms of per capita ESV, Nan'ao County had the largest in 2018, reaching USD 262.30 per person, followed by Dinghai District and Daishan County. In addition, the per capita ESVs in Changhai County, Shengsi County and Putuo District exceeded the average level. Yuhuan city had the lowest per capita ESV at only 38.38 US dollars per person. From the comparison of the economic development and ESV of each island county, the per capita ESVs of all island counties are far less than the per capita GDPs (Table 6).

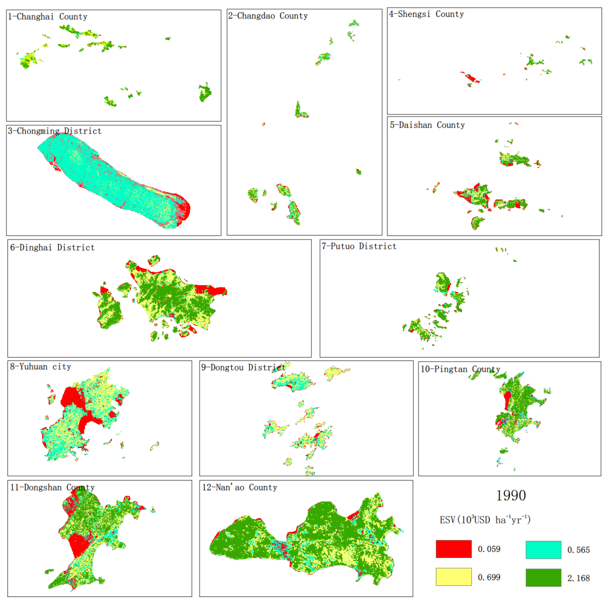

FIGURE 4. Spatial distribution of ESVs in island counties in China in 1990.

From a spatial perspective, the spatial distribution of ESV per hectare also shows differences among the island counties (Figs. 4-7). The ESV per unit area of the eastern islands of Changhai County is higher than that of the western islands, and the ESV per unit area of the western islands is gradually decreasing. The ESVs per unit area of Changdao County, Shengsi County, Daishan County, Putuo District, Dongtou District and Nan'ao County did not change significantly from 1990 to 2018. The ESV per unit area in Chongming District, Dinghai District and Yuhuan city gradually increased over the study period. The ESV per unit area in Pingtan County is gradually decreasing. The ESV per unit area of Dongshan County showed a decreasing trend during 1990-2000 and an increasing trend during 2000-2018.

TABLE 6. ESV, per capita ESV, and per capita GDP (USD) of island counties in China from 1990 to 2018.

Island county	ESV				ESV change rate	2018 ESV/Head (USD yr^{-1})	2018 GDP/Head (USD yr^{-1})
	1990	**2000**	**2010**	**2018**	**1990-2018**		
Changhai	1.76E+07	1.25E+07	1.23E+07	8.26E+06	-53.14%	115.97	20155.66
Changdao	6.44E+06	8.08E+06	7.93E+06	3.31E+06	-48.58%	79.78	27087.99
Chongming	6.28E+07	6.20E+07	6.16E+07	6.85E+07	9.16%	101.03	7826.41
Shengsi	8.51E+06	9.74E+06	7.18E+06	8.90E+06	4.55%	119.64	23219.32
Daishan	3.26E+07	4.03E+07	3.84E+07	2.92E+07	-10.57%	165.51	18458.61
Dinghai	7.64E+07	8.80E+07	8.88E+07	8.49E+07	11.06%	171.13	16720.90
Putuo	6.11E+07	4.91E+07	5.53E+07	5.93E+07	-3.04%	150.85	16818.49
Yuhuan	2.20E+07	2.87E+07	1.61E+07	2.41E+07	9.36%	38.38	13975.15
Dongtou	5.63E+06	4.90E+06	4.86E+06	5.43E+06	-3.54%	53.24	14985.72
Pingtan	4.51E+07	2.74E+07	2.80E+07	3.56E+07	-21.02%	78.81	9462.76
Dongshan	2.51E+07	1.97E+07	2.17E+07	2.34E+07	-6.77%	105.54	17562.88
Nan'ao	1.64E+07	1.94E+07	1.92E+07	2.00E+07	22.03%	262.30	3801.30
Total	3.80E+08	3.70E+08	3.62E+08	3.71E+08	-2.35%		

TABLE 7. ESV sensitivity analysis.

	1990				2000				2010				2018			
	Forest lands	Croplands	Grasslands	Barren lands	Forest lands	Croplands	Grasslands	Barren lands	Forest lands	Croplands	Grasslands	Barren lands	Forest lands	Croplands	Grasslands	Barrer lands
Changhai	0.82	0.12	0.06	0.01	0.58	0.22	0.19	0.01	0.59	0.21	0.20	0.01	0.25	0.32	0.42	0.01
Changdao	0.70	0.19	0.10	0.01	0.85	0.08	0.06	0.01	0.83	0.10	0.07	0.01	0.10	0.41	0.48	0.01
Chongming	0.01	0.09	0.89	0.02	0.04	0.14	0.78	0.04	0.01	0.13	0.83	0.04	0.01	0.09	0.87	0.04
Shengsi	0.81	0.12	0.05	0.02	0.87	0.06	0.05	0.01	0.72	0.18	0.08	0.02	0.74	0.14	0.11	0.01
Daishan	0.80	0.14	0.05	0.01	0.88	0.06	0.05	0.01	0.89	0.05	0.05	0.01	0.71	0.15	0.13	0.01
Dinghaai	0.81	0.16	0.02	0.01	0.89	0.08	0.03	0.01	0.91	0.05	0.03	0.01	0.87	0.07	0.06	0.01
Putuo	0.87	0.10	0.03	0.01	0.76	0.18	0.05	0.01	0.85	0.09	0.05	0.01	0.80	0.18	0.02	0.01
Yuhuan	0.06	0.54	0.37	0.03	0.33	0.49	0.17	0.02	0.01	0.31	0.63	0.06	0.02	0.65	0.32	0.02
Dongtou	0.04	0.60	0.34	0.02	0.07	0.50	0.38	0.05	0.01	0.50	0.47	0.03	0.01	0.52	0.45	0.03
Pingtan	0.83	0.13	0.04	0.01	0.52	0.18	0.29	0.01	0.56	0.22	0.21	0.01	0.66	0.18	0.16	0.01
Dongshan	0.75	0.16	0.08	0.01	0.53	0.30	0.16	0.01	0.64	0.20	0.14	0.01	0.75	0.12	0.12	0.01
Nan'ao	0.84	0.12	0.03	0.01	0.93	0.04	0.02	0.01	0.92	0.05	0.02	0.01	0.95	0.03	0.02	0.01

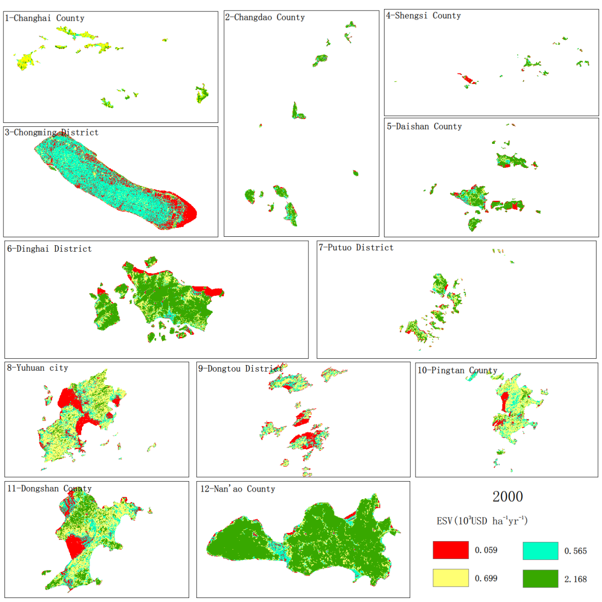

FIGURE 5. Spatial distribution of ESVs in island counties in China in 2000.

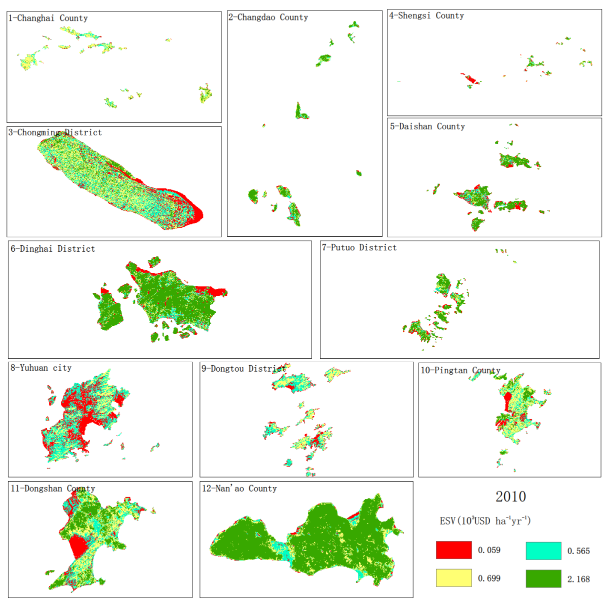

FIGURE 6. Spatial distribution of ESVs in island counties in China in 2010.

C. ESV SENSITIVITY ANALYSIS

Eq. (4) is the calculation formula of ESV sensitivity index, which can be used to measure the dependence of ESV change over time on the value index. If $CS < 1$, it indicates that ESV is inelastic relative to VC, that is, the ecosystem service value is inelastic. The value coefficient is not sensitive, its accuracy

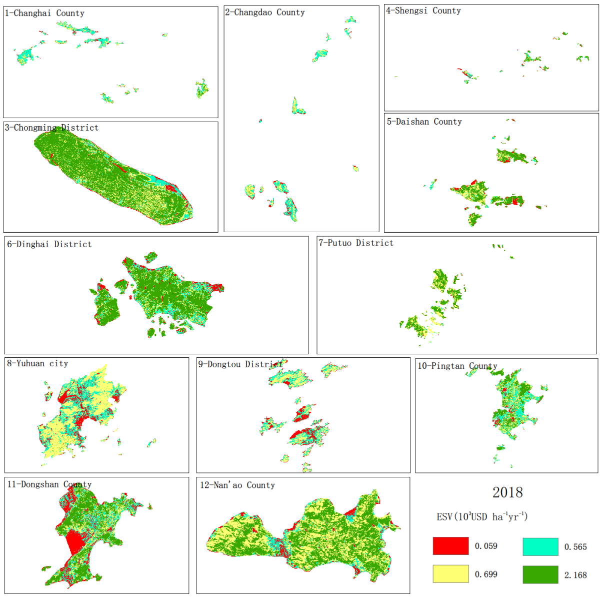

FIGURE 7. Spatial distribution of ESVs in island counties in China in 2018.

TABLE 8. The differences between the two ESV calculation results.

Year	NDVI based ESV (USD yr^{-1})	Supervised classification based ESV (USD yr^{-1})	Difference rate (%)
1990	1.52E+08	1.38E+08	9.21
2000	1.37E+08	1.30E+08	5.11
2010	1.35E+08	1.26E+08	6.67
2018	1.29E+08	1.17E+08	9.30

is high, and the research results are credible; conversely, if CS > 1, it indicates that ESV is sensitive to VC, its accuracy is low, and the result is low in credibility. The ESV sensitivity index has been widely used to measure the scientific of ESV assessment results. Eq. (4) was used to adjust the ESV coefficient of each ecosystem type by 50%; then, the ESV sensitivity coefficients can be calculated for the 12 studied island counties in China. The results are shown in Table 7. The sensitivity coefficient of forestland is the highest among the land cover types, especially in Changhai County and Changdao County. This is because the areas of forestland in these counties allow it to account for the largest proportion of the total ecosystem service value. In Chongming District, grassland has the highest sensitivity coefficient, and in Yuhuan city and Dongtou District, agricultural land has the highest sensitivity coefficient. All the sensitivity coefficients are less than 1, which means that the ESV coefficients of the study area are inelastic, and the research results are credible.

D. COMPARISON OF ESVS OF ISLAND COUNTIES IN CHINA BASED ON SUPERVISED CLASSIFICATION

The comparison of the ESV results of island counties in China from 1990 to 2018, based on supervised classification, is shown in the table below (Table 8). The overall ESV of the island counties in China shows a downward trend from USD 138 million/year in 1990 to USD 117 million/year in 2018. This is in line with the ESV results calculated based on the NDVI. In addition, the ESVs calculated based on the NDVIs are higher than those calculated based on supervised classification, with difference rates between 5.11% and 9.30%. The year 2000 saw the highest difference rate of 5.11%, while the year 2018 saw the lowest difference rate, at 9.30%.

IV. DISCUSSION AND IMPLICATIONS

A. LIMITATION AND ACCURACY OF ESV CALCULATIONS BASED ON NDVI

The normalized difference vegetation index (NDVI) is a common index that measures regional vegetation cover. And vegetation is the main body and structural basis of island-mainland ecosystems. Therefore, we used NDVI to measure the vegetation coverage of the island area and reflect the ecological conditions of the island area from the main aspects. Ecosystem service value is a measure of the economic value of the direct or indirect products and services produced by the ecosystem through its functions. ESV can reflect the quality of ecosystem services in island areas as a whole. This paper uses both NDVI and ESV to assess the ecosystem of island cities, which is helpful for a more comprehensive analysis of the ecological environment of island cities. However, this study still has the following limitations.

Although radiometric calibration and atmospheric correction have been carried out on Landsat remote sensing images, the calculated NDVIs are still subject to uncertainties caused by clouds and water vapor. In this paper, the NDVI values of forestland, cultivated land, grassland, and barren land (non-vegetated, including all land with NDVIs less than 0.1) are used to calculate the ESV of a given island. However, non-vegetation ecosystems also include different ecosystem types, such as water bodies, buildings, and wetlands, which limits the accuracy of ESV calculations to a certain extent. Furthermore, the ESVs of island counties in China are calculated based on the supervised classification of remote sensing images, and the calculation results differ from those calculated based on the NDVIs in the range of 5.11% - 9.30%, indicating that the ESV calculation based on the NDVI has a high accuracy. The accuracy of ESV calculations of island counties can be improved through the integration of remote sensing technology and field observations.

B. INFLUENCING FACTORS OF ECOSYSTEM SERVICE VALUE CHANGES IN ISLAND CITIES

From 1990 to 2018, the average NDVI of China's 12 island counties showed a continuous downward trend, and the decline in NDVI of 2/3 island counties was particularly significant. The first reason is the continuous expansion of island construction land, over-development has led to a large area of forest reduction, and the overall vegetation coverage has shown a downward trend; the second reason is the island counties' ecosystems are relatively fragile, with weak self-recovery capabilities, and damage caused by irrational development is difficult to recover to the original state.

The total ESV of China's island counties from 1990 to 2018 showed a ''V''-shaped change, with the lowest value of USD 789 million in 2010. Forest is the primary factor affecting the vegetation coverage of islands, and the reduction of forest ecosystem service value is the driving factor for the reduction of ESV in island counties in China. The ESV coefficients of farmland, grassland and construction land in the 12 island counties are low, while that of forestland is high [44]. The ESV of forestland decreased by 11.27% over the study period, while those of farmland, grassland and barren land increased by 1.30%, 21.15% and 20.26%, respectively, from 1990-2018. This also proves that forestlands are the main driving factor affecting changes in the ecosystem service values of the island cities.

There are regional differences in the spatial distribution of NDVI and ESV in the island counties, but on the whole they present the spatial characteristics of high center and low edge. This is related to the island's topography and the characteristics of the ecosystem. Due to the long-term impact of sea wind and waves on the edge of the island, the vegetation coverage rate will generally be lower than that of the central island, and the ecosystem service value is relatively low. In addition, the ESV sensitivity coefficient calculation results are all less than 1, indicating that the ecosystem service value is not sensitive to the value coefficient, its accuracy is high. And through the calculation of ESV sensitivity coefficient, the credibility of the research results is improved.

We think that there are two main reasons for the deterioration of the ecological environment of the island cities: first, with the rapid economic development and urbanization of the island counties, the land area used for construction continues to expand, and excessive development leads to significant reductions in forest and grassland areas, which in turn results in decreasing vegetation cover overall; urbanization-led land use changes have profoundly affected ecosystem services [26], [45]. Second, island county ecosystems are vulnerable and are not resilient, which makes it difficult to restore areas that have undergone damage caused by unreasonable development to their original states.

C. ECOLOGICAL GOVERNANCE AND SUSTAINABLE DEVELOPMENT OF ISLAND CITIES

As complex systems of both land and sea spaces, island cities have become an important platform for promoting land and sea coordination, protecting the marine environment, and maintaining ecological balance. A sound island ecosystem is an important pillar for the sustainable economic and social development of island cities, and the construction of island ecological conservation is the top priority of island city governance. Based on the evaluation of the ecosystem service value of 12 island cities in China, the article found that the construction land of island cities is over-expanding, while the protection of vegetation and forest ecosystems is a challenge, and it is the main factor affecting the ecological environment of island cities. In the ecological governance of island cities, it is necessary to focus on the protection of forests and grasslands to increase the vegetation coverage of islands and simultaneously control the expansion of urban construction land. Human intervention should be carried out on island areas that have been damaged, and island ecological restoration projects should be carried out to restore island vegetation and improve the sustainable development of island cities.

V. CONCLUSION

This study analyzes the temporal and spatial evolution of NDVI and ecosystem service value in China's island counties in 1990-2018 using Landsat remote-sensing images. The conclusion as follows:

(1) From 1990 to 2018, the total ESV of China's island cities showed a ''V''-shaped change trend

From 1990 to 2010, the ESV of island cities showed an overall downward trend. The main reason is that the rapid development of island cities and the intensification of human activities have led to the rapid increase of urban construction area in island areas and the continuous reduction of vegetation coverage, which has reduced the value of the island city's ecosystem services. In 2010-2018, the government's emphasis on and investment in the ecological environment continued to increase, especially the protection and restoration of vegetation in island areas, which eased the trend of vegetation decline in island areas, and developed grassland and other artificial greening. In addition, urban construction has also been restricted and more scientifically planned. Therefore, ESV has increased to a certain extent.

(2) The ESV of each island city showed regional differences

The ecosystem service value and its temporal and spatial distribution of the 12 island cities all show significant differences, which are related to the topography of the island, its geographic location, climatic characteristics, and the degree of development and utilization of each island city. But in general, the ecosystem service value of the fringe areas of the island cities is generally lower than that of the central area. On the one hand, the reason is that the edge of the island is easily disturbed by sea wind and waves; on the other hand, human activities and urban construction are mostly concentrated in the edge of the island, resulting in significantly lower vegetation coverage in the edge of the island than in the central area.

(3) Forest is the main driving factor of ESV changes in island cities

Among the various types of land cover, the forest covers the largest area, reaching more than 60% overall. Moreover, forests have the highest value of ecosystem services, and changes in forest area will largely affect the overall changes in the value of ecosystem services in island cities. Therefore, the government should increase investment in island ecological protection, protect and restore island vegetation, and control the expansion speed of island cities.

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